A SUPERCONDUCTING UNDULATOR AT THE 500 MEV RF-GUN DRIVEN LINAC-RECIRCULATOR AT MAX-LAB

E. Wallén†, M. Eriksson,MAX-Laboratory, University of Lund, Lund, Sweden
R. Rossmanith, Forschungszentrum Karlsruhe, Karlsruhe, Germany

Abstract

MAX-lab is replacing its microtron injector with an RF-gun driven 500 MeV recirculator linac (250 MeV linac with one recirculation). The linac will later be equipped with a low emittance laser gun. In this paper a future installation of a superconducting undulator driven by the recirculator beam is discussed. The undulator will be characterised by the emission of spontaneous undulator radiation. The light pulses from the spontaneous undulator radiation are relatively short, on the order of 1 pS, and there may be some experimental applications of the emitted light. In a later stage the superconducting undulator will be used as a radiator in an optical klystron. The optical klystron is expected to produce coherent light in the 20 nm wavelength region with a brilliance that is several orders of magnitude higher than the spontaneous emission, and it may be tuneable if we put the energy modulator in the recirculating path of the injector.

1 INTRODUCTION

The experimental set-up described in this article is closely related to the design of MAX IV, a new 3 GeV electron storage ring with full energy injector at MAX-lab [1]. The MAX IV design builds to a large extent on the use of short period superconducting undulators which are capable of producing high fluxes of x-rays in the 10-20 keV region. Superconducting short period undulators are not yet in routine operation at any synchrotron radiation source even though promising initial work has been carried out [2,3]. The aim of this project is to develop and build a short period undulator similar to the undulators that will be part of the MAX IV system and also characterise the undulator with the help of the emitted light when an electron beam from the new 500 MeV injector [4] is passing through the undulator.

The MAX IV injector system, which is a recirculated linac with energy recovery, will be used for the production of coherent light at short wavelengths in an arrangement of cascaded optical klystrons. It is planned that the superconducting undulator in the experimental programme described in this article will be used as a radiator in a one stage optical klystron in order to demonstrate the performance of the optical klystron concept. In such a set-up, there is a need for an additional permanent magnet undulator and a seed laser in order to create a micro-bunching of the beam before the beam enters the radiator, where coherent light is emitted.

The set-up with a superconducting undulator will be situated on the floor inside the MAX II ring at MAX-lab. There is 22 m of free floor space available for the set-up. The beam is parallel to the floor 40 cm up from the floor level which puts some constraints on the design of the cryostat in which the superconducting undulator is situated.

2 500 MEV LINAC-RECIRCULATOR

Figure 1 shows the new 500 MeV RF-gun driven linac-recirculator. The injector system consists of two 5.2-m, 3-GHz acceleration sections and a SLED system. Each section will give an energy gain of 125 MeV and the two sections will be recirculated once to give a total of 500 MeV. The linac will be injected from a 2.3 MeV RF gun with a photo-cathode. The total circumference of this system is 30 m or 100 ns. The parameter list of the injector system operating with a photo-cathode RF gun is shown in Table 1. It should be noted that the development of the photo-cathode RF gun is part of the project and the numbers stated in table 1 are the expected parameters of the future photo-cathode gun.

Table 1: parameter list of the injector

Electron energy	500 MeV
Charge/pulse	1 nC
Pulse length	1 pS
Normalised emittance	2 mm mrad
Repetition rate	10 Hz
Pulse energy spread	0.2 %
Sliced energy spread	0.01 %

3 SUPERCONDUCTING UNDULATOR

The superconducting undulator should in principle be identical to the undulators included in the MAX IV design, where undulators with a period length of 12 mm and 200 periods are proposed. The period length should hence be 12 mm and the number of periods is 200. The gap is 3.4 mm making it possible to adjust the K value of the undulator to any value between 0 and 2.3. The cold length is hence 2.4 m. The warm length of the cryostat should be less than the 3.6 m long straight sections of MAX IV. There is today no existing undulator that meets these criteria and the design and construction of such an undulator, including the cryostat and cryogenic system, will be the major part of this project. The working principles of the new superconducting undulator will be based on the experience gained at Forschungszentrum

. †erik.wallen@maxlab.lu.se

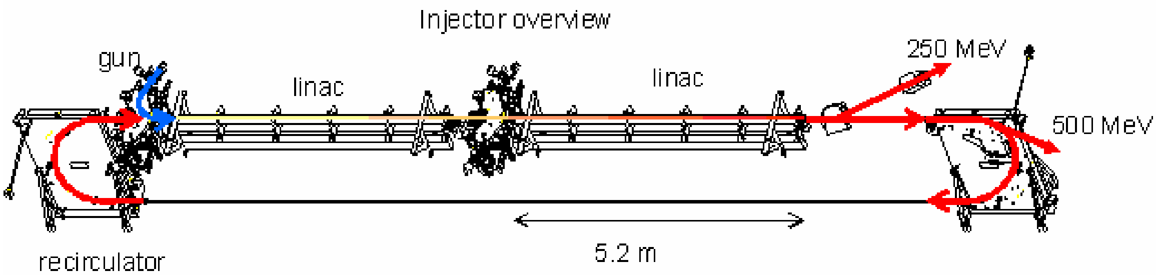

Figure 1. The 500 MeV RF-gun driven linac-recirculator injector at MAX-lab

Karlsruhe from short period superconducting undulators [2,3] and at MAX-lab from the construction of a cold bore superconducting multi-pole wiggler [5].

4 SPONTANEOUS EMISSION

The undulator will be characterised by the undulator radiation that is emitted when the 500 MeV electron beam passes through the undulator. We foresee a simple beam line set up in order to scan through the energy span of the emitted light. The K-value of the undulator can be put to any value between 0 and 2.3 by varying the excitation current of the superconducting wire. The fundamental tone of the undulator at K equal to 1 corresponds to a wavelength of 9.4 nm or a photon energy of 132 eV. The peak brilliance of the undulator is shown in Figure 2, which includes up to the 11:th overtone.

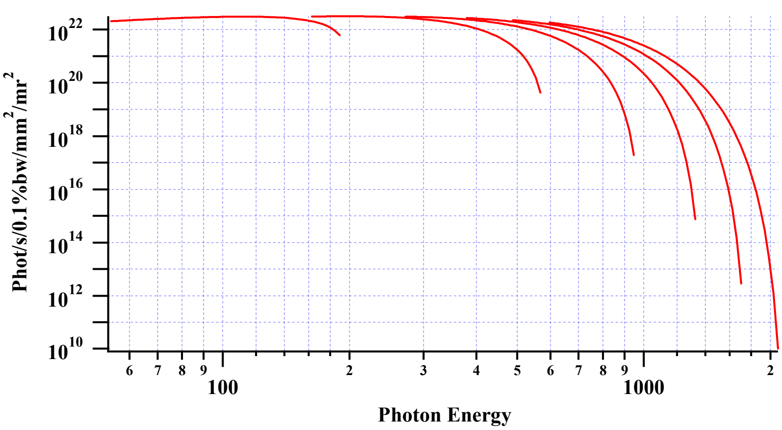

Figure 2. Peak brilliance: I =1000 A (1 nC in 1 psec). Spontaneous emission. Period length 12 mm, length 2.4 m, k between 0 and 2.3.

5 COHERENT EMISSION

The flux of photons can be increased several orders of magnitude by inducing a micro-bunch structure in the electron bunch. If the micro-bunches are shorter than the wavelength of the emitted light the electrons within the micro-bunch will radiate coherently. Moreover if the micro-bunches are equally spaced with a distance corresponding to a multiple of the undulator wavelength, the micro-bunches will interact and emit light coherently. A properly micro-bunched beam delivers not only more photons but also within a narrower bandwidth than a beam without micro-bunching.

5.1 SASE FEL

To obtain saturation in self amplified spontaneous emission free electron lasers, SASE FELs, there is a need for about 600 undulator periods. The present plans include one superconducting undulator with 200 periods, which is not sufficient to obtain saturation and there are at present no plans for trying to reach saturation in a SASE FEL process within this project. The plans may change if there are resources available for building more than one superconducting undulator. We hope, however, to produce coherent light in an optical klystron process where the superconducting undulator is used as a radiator.

5.2 OPTICAL KLYSTRON

The optical klystron concept builds on the principle that a micro-bunched beam is created by letting the electron beam pass a moderator and a dispersive section. The micro-bunched beam will then enter the radiator, which in this case is the superconducting undulator, and coherent light will be emitted.

The moderator is a permanent magnet undulator with a seed laser that is matched to the electron beam so it envelopes its as it passes through the moderator. The fundamental undulator radiation wavelength of the moderator is identical to the laser wavelength. The strong electric fields from the laser modulate the energy of the electrons in the bunch as they are oscillating in the moderator. The energy modulation is then, after passing the dispersive section, turned into an intensity variation, i.e. micro-bunching, with a period length equalling the seed laser. The dispersive section can be a chicane and the matching should be done so that optimum bunching occurs in the middle of the radiator.

Since the radiator operates at shorter wavelengths than the modulator, it is essential to get the micro-bunches shorter than the wavelength of the fundamental tone of the radiator. It is hence important to get a strong energy modulation in the moderator, exceeding the sliced energy spread in the electron bunch by a factor larger than the wavelength ratio between the moderator and radiator.

The Seed laser we foresee to use is a Nd:Yag operating at the 5th overtone. The wavelength is 212 nm and the pulse length 5 ns with full temporal coherence and the power is 10 MW during the pulse. We hope, if necessary, to be able to compress the pulse to less than 1 nS in order to increase the peak power to 50-100 MW. We are aiming at producing coherent light at the 11th overtone of the seed laser, i.e. 19.3 nm. The superconducting undulator will thus be put to a K-value of 2, which would make it possible to produce coherent light at the third harmonic of the radiator, i.e. the 33rd harmonic of the seed laser.

We see two alternative locations for the moderator, in line with the radiator moderating at the 500 MeV electron beam or in the recirculating path of the injector moderating at 250 MeV.

5.2.1 Moderator at 500 MeV

A moderator for the 500 MeV beam could typically be 4.2 m long and have a period length of 14 cm. With the moderator operating at 500 MeV we need a high laser power, on the order of 100 MW, in order to obtain a sufficiently strong energy modulation. The dispersive section consists of a chicane between the moderator and radiator. There is up to 22 m of length available on the floor in the centre of the MAX II ring for such a set-up.

The wavelength of the emitted coherent light in the radiator is locked to a harmonic of the seed laser and the bandwidth of the emitted coherent light is given by the number of periods of the coherent light that there is room for over the whole electron bunch, since we expect full coherence over the whole train of micro-bunches in the electron bunch. The bandwidth for 19.3 nm coherent peak is hence 6×10^{-5} and we expect a peak brilliance that is more than a factor 10^6 higher than the peak brilliance of the spontaneous radiation. Due to the strong energy modulation it is only about one third of the 200 periods in the radiator that will contribute to the coherent radiation.

5.2.2 Moderator at 250 MeV

By putting the modulator in the recirculating path of the injector and modulating the 250 MeV the demands for high power of the laser light is somewhat reduced since we can use a moderator with shorter period length and more periods than at 500 MeV and the transverse motion of the electrons in the moderator, which induces the energy modulation, is larger for the same K-value.

The 180 degree bend in the injector are achromatic but there is after the second passage through the linac structure a transport line up to the MAX II floor and the radiator that has some dispersion and the need for a chicane might be eliminated.

An attractive feature of making the energy modulation before the second passage through the linac is that we can introduce a macroscopic energy modulation of the whole electron bunch by varying the phase of the linac, with a linear energy variation from the beginning to the end of the bunch, thus giving a compression or decompression of the electron bunch as it passes the dispersive transport line to the radiator. The optical klystron is then no longer mode locked to harmonics of the seed laser. It is enough to vary the bunch length with just a few percent to be able to have a tuneable optical klystron that produces coherent light without the spikiness that appears in a SASE FEL due to the start up from a noise signal.

This paper describes the current ideas for an experimental set-up using the superconducting undulator. A substantial amount of work has to be done to further study a number of areas, e.g. the matching of laser light and beam envelopes, the design of the dispersive section and transport line for the electron beam, and the laser installation and triggering systems to get proper phasing between laser pulse and electron bunch. It must be remembered though that the major goal of this project is to construct, build and characterize a superconducting undulator that can be part of the MAX IV accelerator system.

REFERENCES

[1] M. Eriksson, Å. Andersson, S. Biedron, M. Demirkan, G. LeBlanc, L.-J. Lindgren, L. Malmgren, H. Tarawneh, E. Wallén, S. Werin, " MAX4, a 3 GeV Light Source with a Flexible Injector", EPAC 2002 Paris, June 2002, Poster ID: TUPLE005.

[2] H.O. Moser, R. Rossmanith, "Magnetic field of superconductive in-vacuo undulators in comparison with permanent magnet undulators". Apr 2002 e-Print Archive: physics/0204037, Nuclear Instruments and Meth. A, in press.

[3] R. Rossmanith, H.O. Moser,"Design study of a superconductive in-vacuo undulator for storage rings with an electrical tenability between K=0 and 2", EPAC 2000, Vienna, June 2000.

[4] S. Werin, Å. Andersson, M. Demirkan, M. Eriksson, G. LeBlanc, L.-J. Lindgren, L. Malmgren, "Status of the New Injector for MAX-lab" EPAC 2002 Paris, June 2002, Poster ID: 304 - TUPLE006.

[5] G. LeBlanc, E. Wallén," Evaluation of the MAX Wiggler", EPAC 2002 Paris, June 2002, poster ID: TUPLE035.